AFRL

AEPW-4 HIGH-SPEED WORKING GROUP

AN OVERVIEW OF RECENT PROGRESS AND FUTURE DIRECTIONS

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AIAA AVIATION – AEROELASTIC PREDICTION WORKSHOP

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HSWG Key Questions

Objective: Assess the SoA of aerothermoelastic toolsets in high-speed applications

- What are the physical mechanisms that drive the various types of aerothermoelastic instabilities in high-speed flows?
- How accurately can dynamic aerothermoelastic instabilities be calculated? (Identifying onset of the instability vs the post-threshold behavior)
- Develop guidelines/metrics for modeling instabilities: What level of model fidelity is required? How much accuracy is lost when using lower fidelity methods?
- What is the uncertainty in our models? How does uncertainty propagate when coupling multiple models?
- What are the gaps/uncertainties in current experimental datasets that need to be addressed with follow-on or new experiments?
- How well do the SoA models handle complex structures and flow environments (transition, separation, SBLI, 3-D effects)?

HSWG Update Overview & Progress Towards Objectives

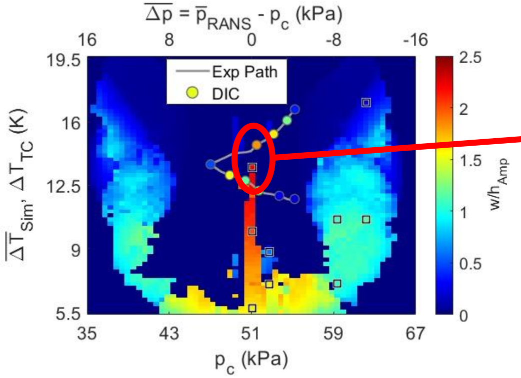
- Selected challenge problems:
  - RC-19: Large-amplitude, nonlinear dynamics of a thin panel with and without SBLI
  - HyMAX: Linear response of a cantilevered plate to transitional, separated SBLI
- HSWG off-cycle relative to other working groups under AePW
  - First formal workshop held at SciTech 2023 (informal meetup in 2024)
  - Monthly meetings throughout 2024/2025 highlighting participants' progress
- Current participation: 109 members on the email chain, 8 groups working on RC-19, 5 groups working on HyMAX
- ***Near term:*** Wrap up current iteration by SciTech 2026 (presentation of results/lessons learned)
- ***Long term:*** Selection of follow-on challenge problem

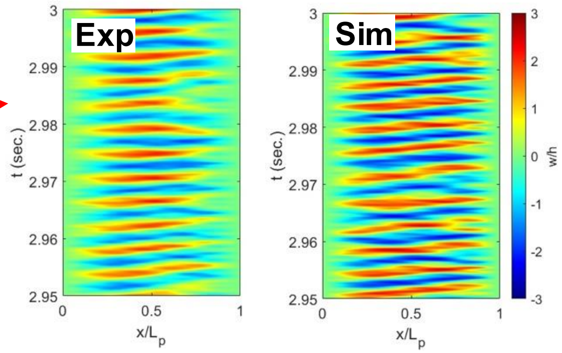
	AFRL-SSC	Duke	NASA	DLR	UNSW	MIT	Stevens	UC/ARL	Metacomp	Hexagon
RC-19	✓	✓	✓	✓	✓			✓	✓	✓
HyMAX		✓			✓	✓	✓	✓		

HSWG Participant Highlights/Results: RC-19 Without SBLI

AFRL Fluid + Structural ROMs

Coupled simulations with variable p_c and ΔT

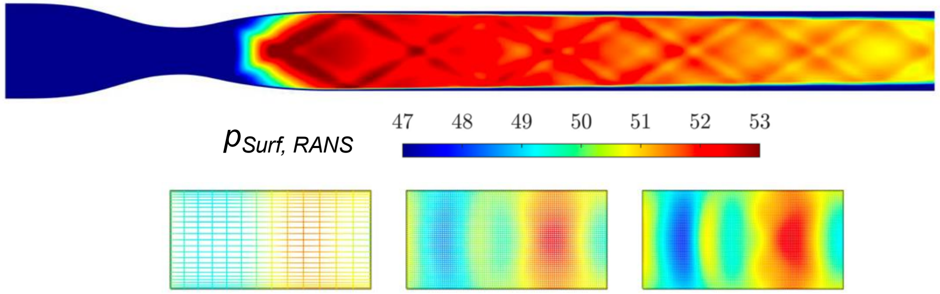




Brouwer et al., ND 2021

NASA FUN3D (and PT) + FEA

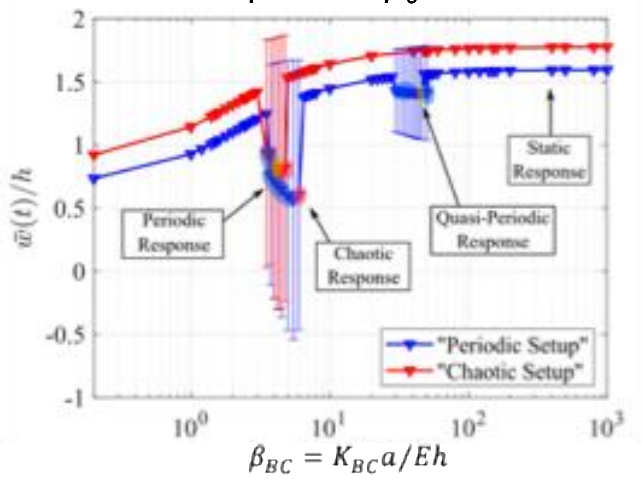
Rigid simulations of test section prior to coupled simulations



Stanford, AePW HSWG 2024

Duke Fluid + Structural ROMs

Specified p_c and ΔT with variable stiffness BC



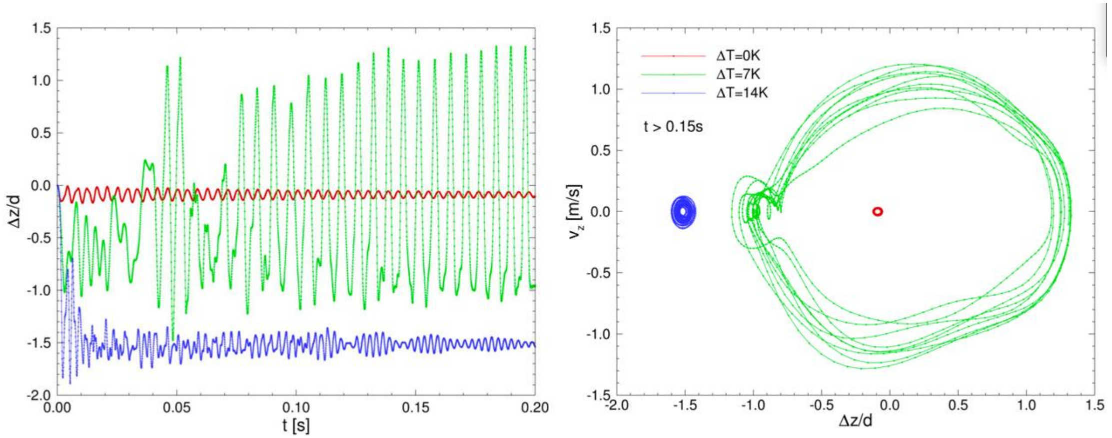
Periodic Parameters		Chaotic Parameters	
Δp (kPa)	3.91	Δp (kPa)	5.01
ΔT (K)	12.8	ΔT (K)	14.7

Boundary support parameter (β_{BC}) determined from benchtop vibration test or FEA

Piccolo Serafim et al., JFS 2023

DLR URANS + FEA

No structural damping with specified *ΔT and* modeled p_c

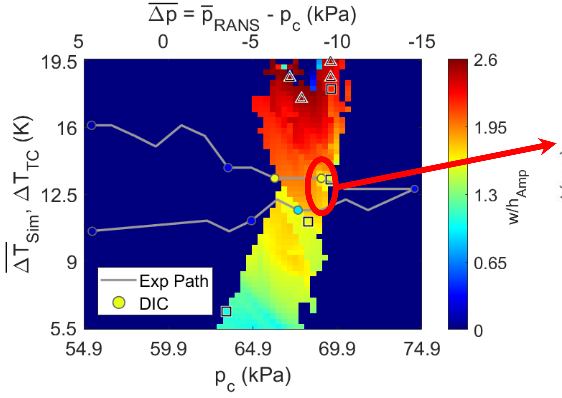


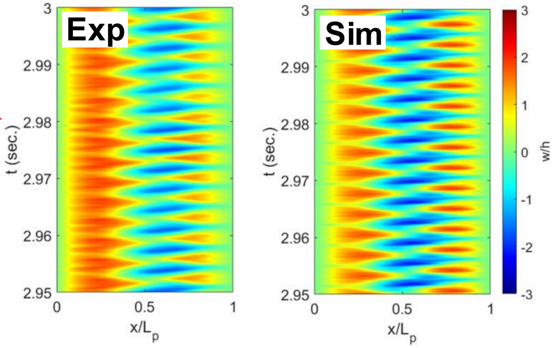
Reiman, AePW HSWG 2024

HSWG Participant Highlights/Results: RC-19 with SBLI

AFRL Fluid + Structural ROMs

Coupled simulations with variable p_c and ΔT



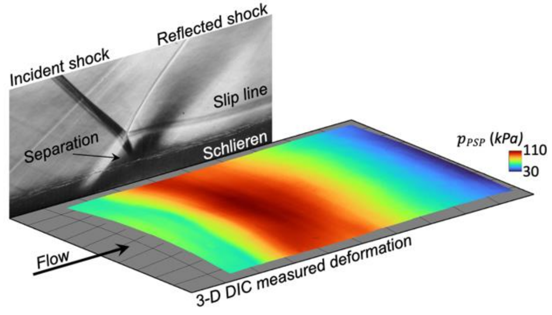


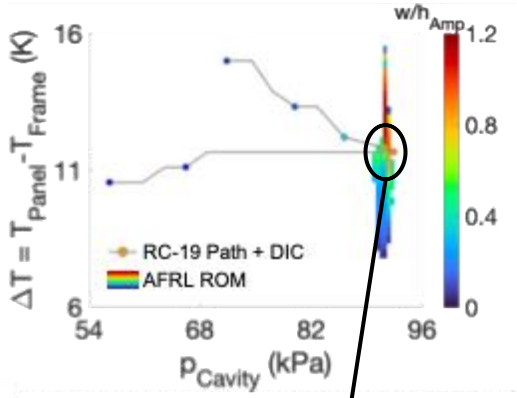
Brouwer et al., JFS 2021

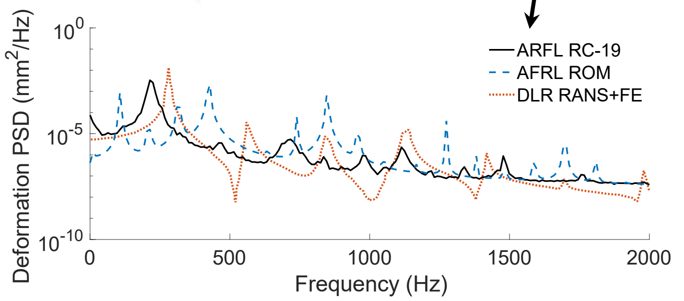
Separated SBLI (Not Officially Part of AePW)

AFRL Fluid + Structural ROMs

DLR URANS + FEA



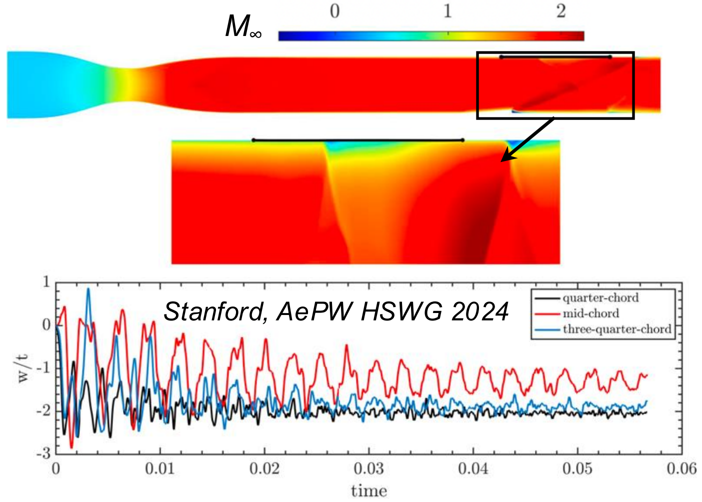




Reimann, AePW HSWG 2024

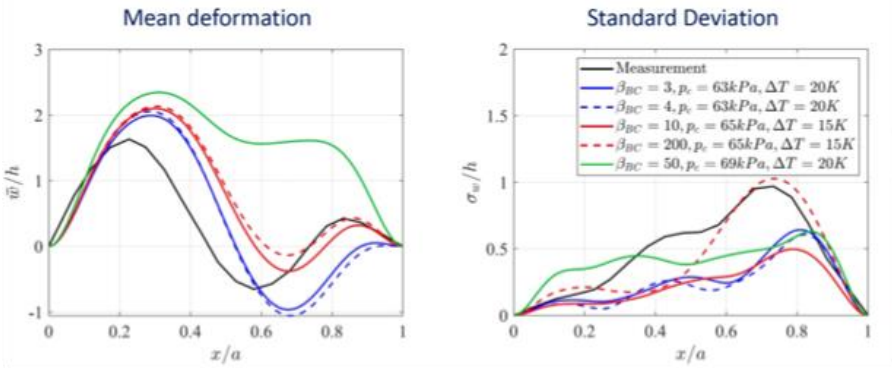
NASA FUN3D (and PT) + FEA

Coupled simulations with specified p_c and ΔT



Duke Fluid + Structural ROMs

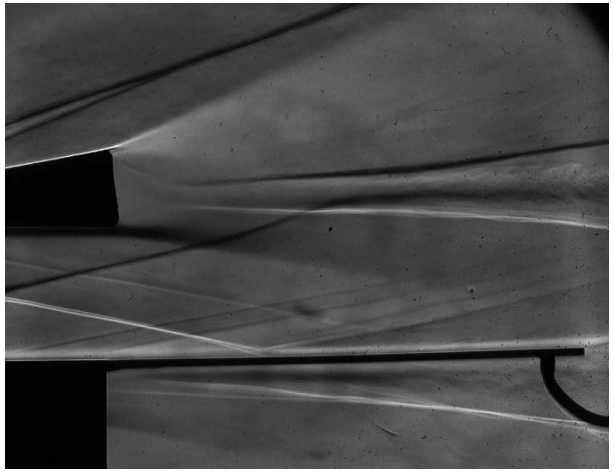
Variable p_c, ΔT, and stiffness BC



Piccolo Serafim et al., AIAA Aviation 2025

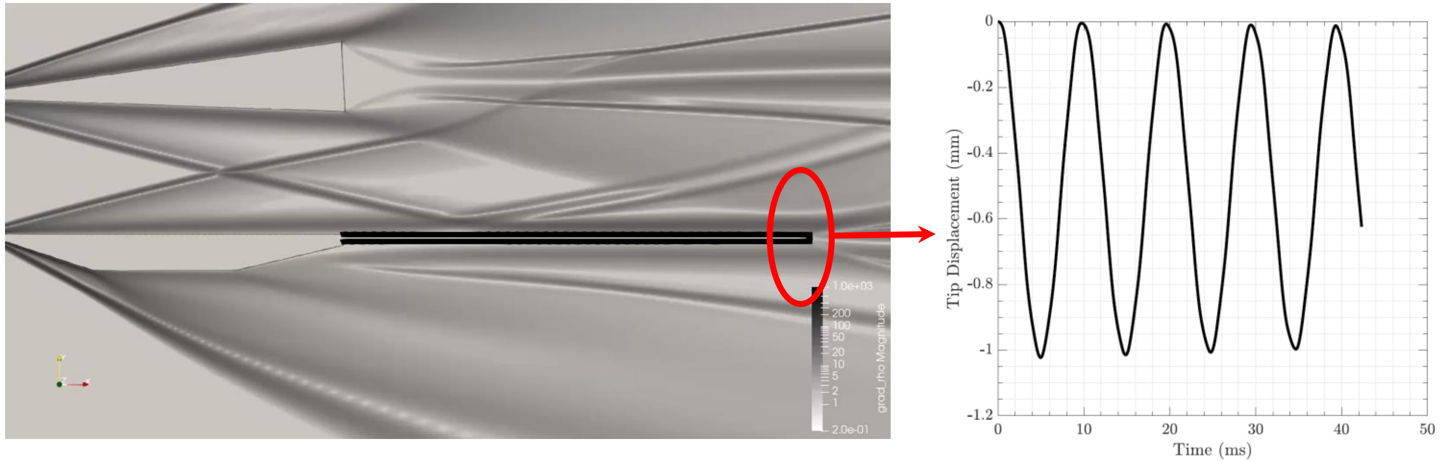
HSWG Participant Highlights/Results: HyMAX

UNSW HyMAX Schlieren



Stevens AERO-F + AERO-S

Numerical Schlieren and tip displacement for preliminary coupled simulations



Rabinovitch, AePW HSWG 2025

Note: Limited simulations for this case due to complicated, transient, shock dominated flow field (includes unsteady inflow conditions, separation, and transitional SBLI depending on shock strength) + linear structural response

HSWG Lessons Learned

- Low fidelity toolsets (Enriched piston & potential flow theories + structural ROMs) offer good balance of efficiency and predictive accuracy
  - Accurately predict onset of instabilities, but do not always accurately capture post-threshold response
  - Computational efficiency enables exploration of vast parameter space and more detailed mapping of instabilities
  - Tend to require less data from experiments to setup/initialize
- High-fidelity simulations (CFD + FEA)
  - Require additional data to setup/initialize – especially CFD (e.g., inflow BC, nozzle/test section geometry)
  - Computational expense limits computed time histories (problem for long-duration FSI phenomena)
  - Higher fidelity likely needed for separated SBLI cases – particularly if flow unsteadiness plays a role
  - Computational expense limits the number of parameter combinations – complicates direct comparison of simulations and experiments given input parameter uncertainties
- Limited use of data-driven multi-fidelity methods to tackle these challenge problems
- Additional needs from experiments:
  - Temperature field characterization (especially for buckled panels)
  - Improved characterization of configuration setup
    - Structural boundary conditions after install which can alter frequency characteristics
    - Test section inflow conditions
  - Improved baseline (no structural deformation) flow characterization for fluid model validation

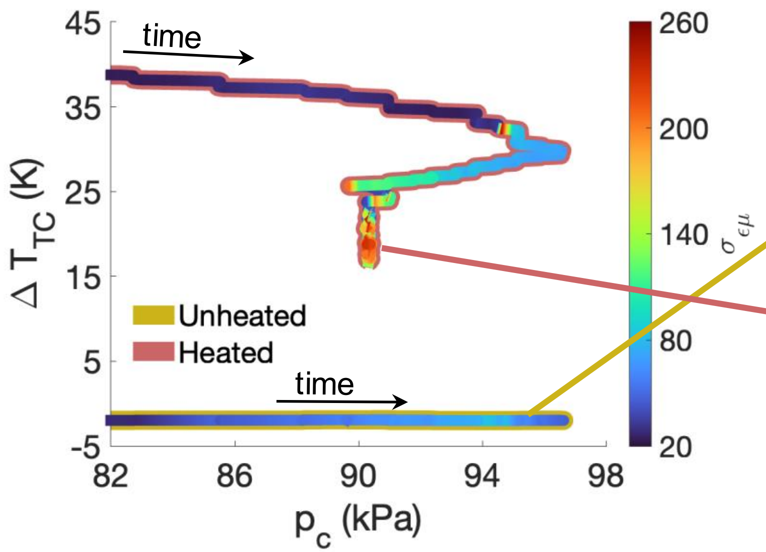
HSWG Future Directions

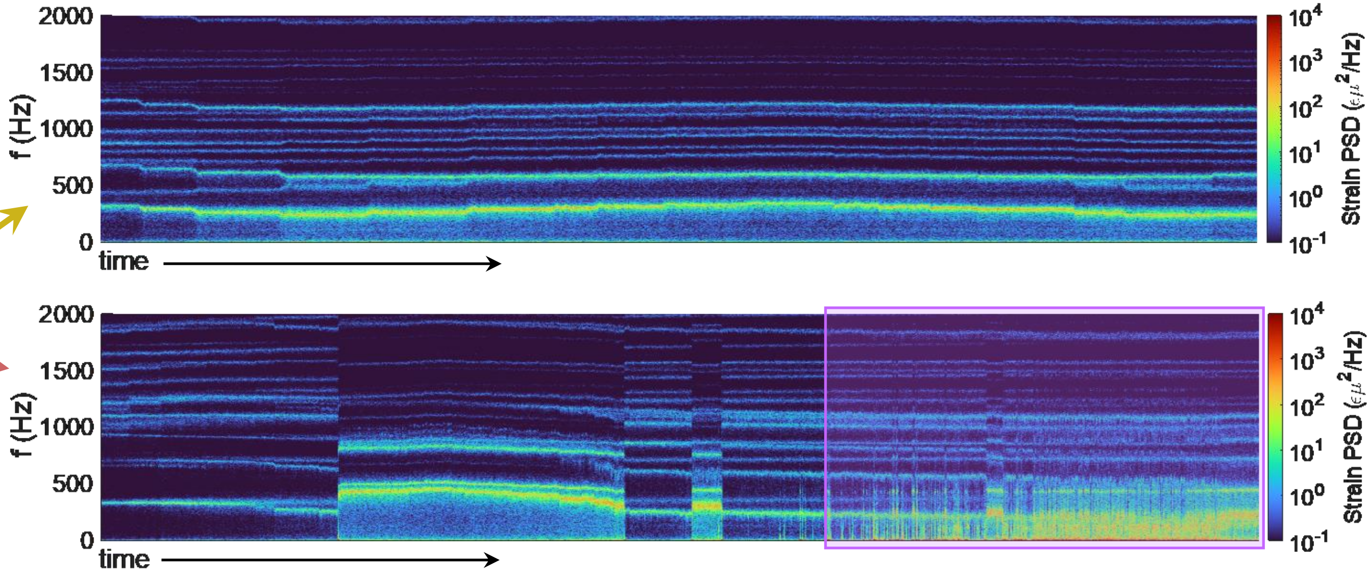
- AFRL-Supported AE/ATE Experiments (Packaged consistent with RC-19 challenge problem):
  - RC-19 updates: Separated SBLI with snap-through & swept, attached SBLI with multiple instabilities
  - M6HRF: Compliant panel tests with quasi-static and dynamic responses (Led by Zach Riley)
  - H2K: Separated (transitional/turbulent) SBLI-induced aeroelastic experiments (Collaboration with DLR)

- Variations of HyMAX
  - Plans to test a similar configuration to HyMAX in the AFRL M6HRF
  - Will allow for longer flow times, *O(min)*, with the potential to observe flutter in the presence of thermal effects

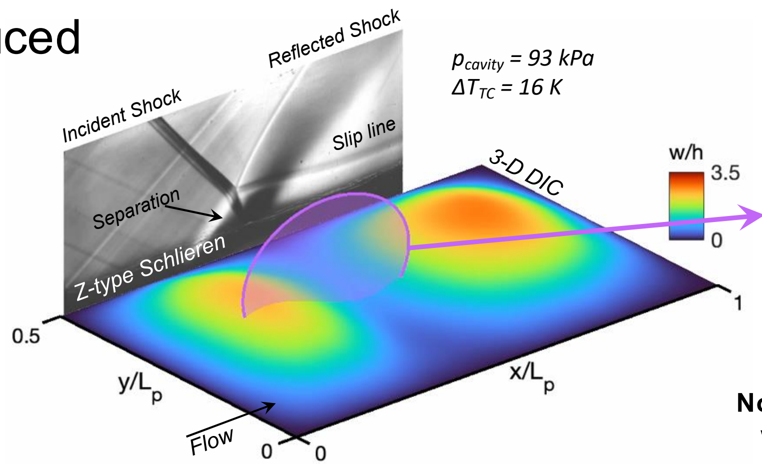
- Other experiments/Inputs from AePW HSWG participants/AIAA FSI DG?

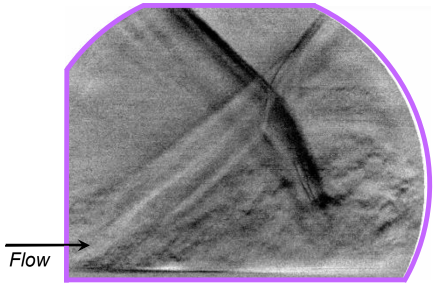
RC-19 Updates: Snap-through Excited by a Separated SBLI





- ***Key aeroelastic instability***: TBL + Separated SBLI-induced intermittent/continuous snap-through of buckled panel
- Measurements available:
  - Pre-test panel characterization
  - Discrete: TCs, strain gauge, cavity pressure
  - Full-field: DIC, FLIR, PSP (unheated, rigid only), SAFS

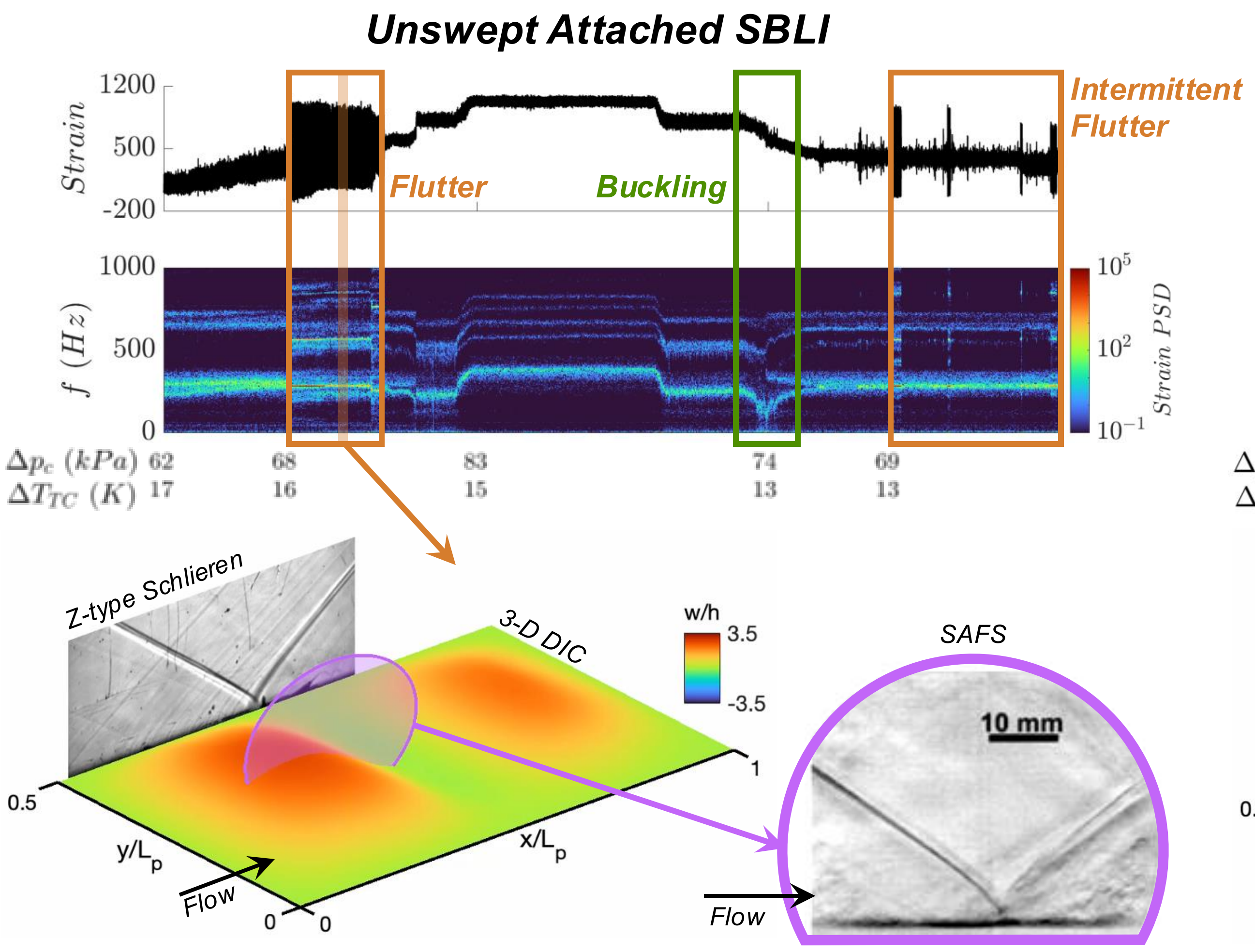


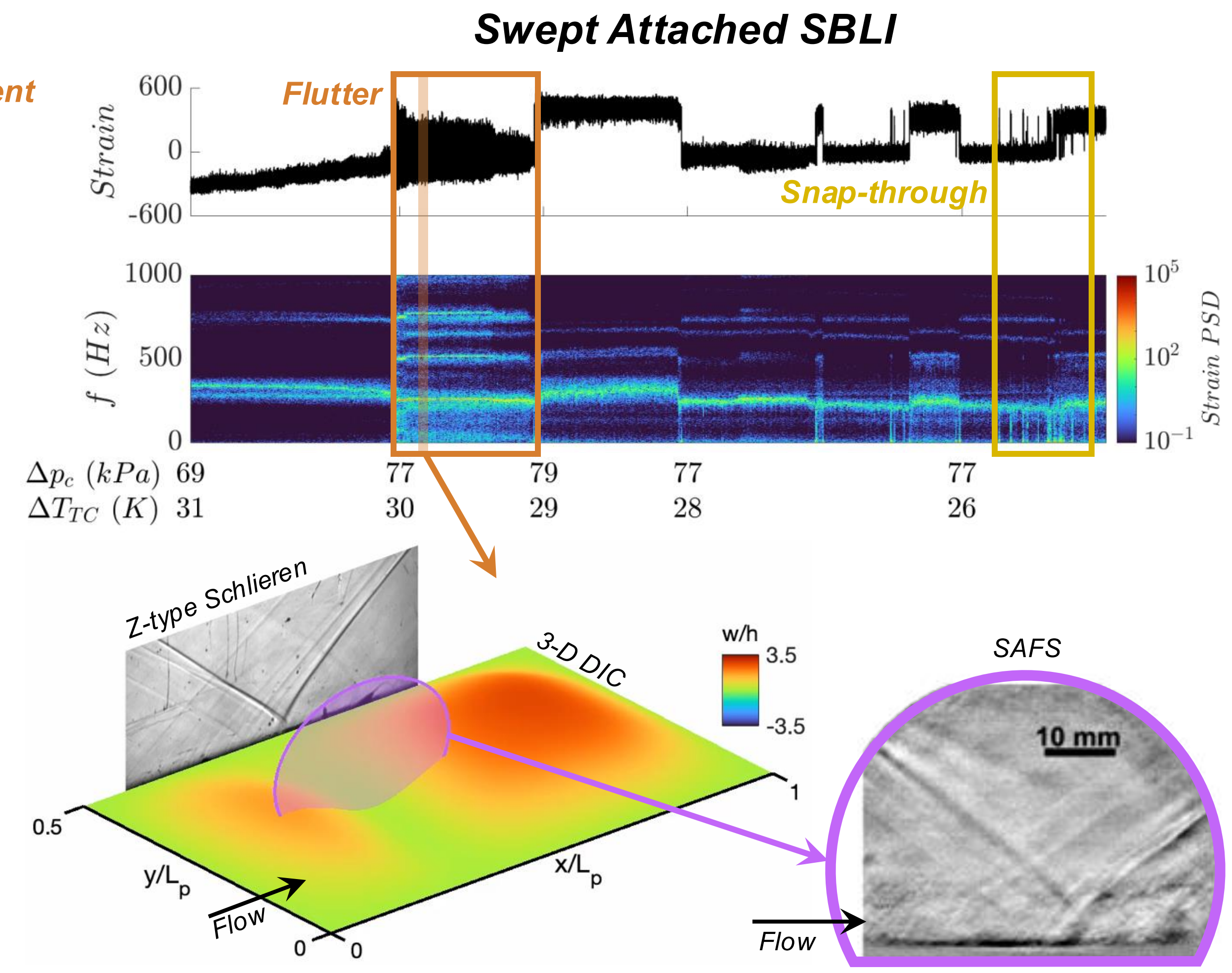


SAFS along midspan plane
(recorded simultaneously with DIC)

Note: IR also recorded simultaneously with SAFS and DIC but is not shown

RC-19 Updates: Effect of Incident Shock Sweep on Aeroelastic Instabilities





Note: IR also recorded simultaneously

HSWG Future Directions: AFRL M6HRF Challenge Problem

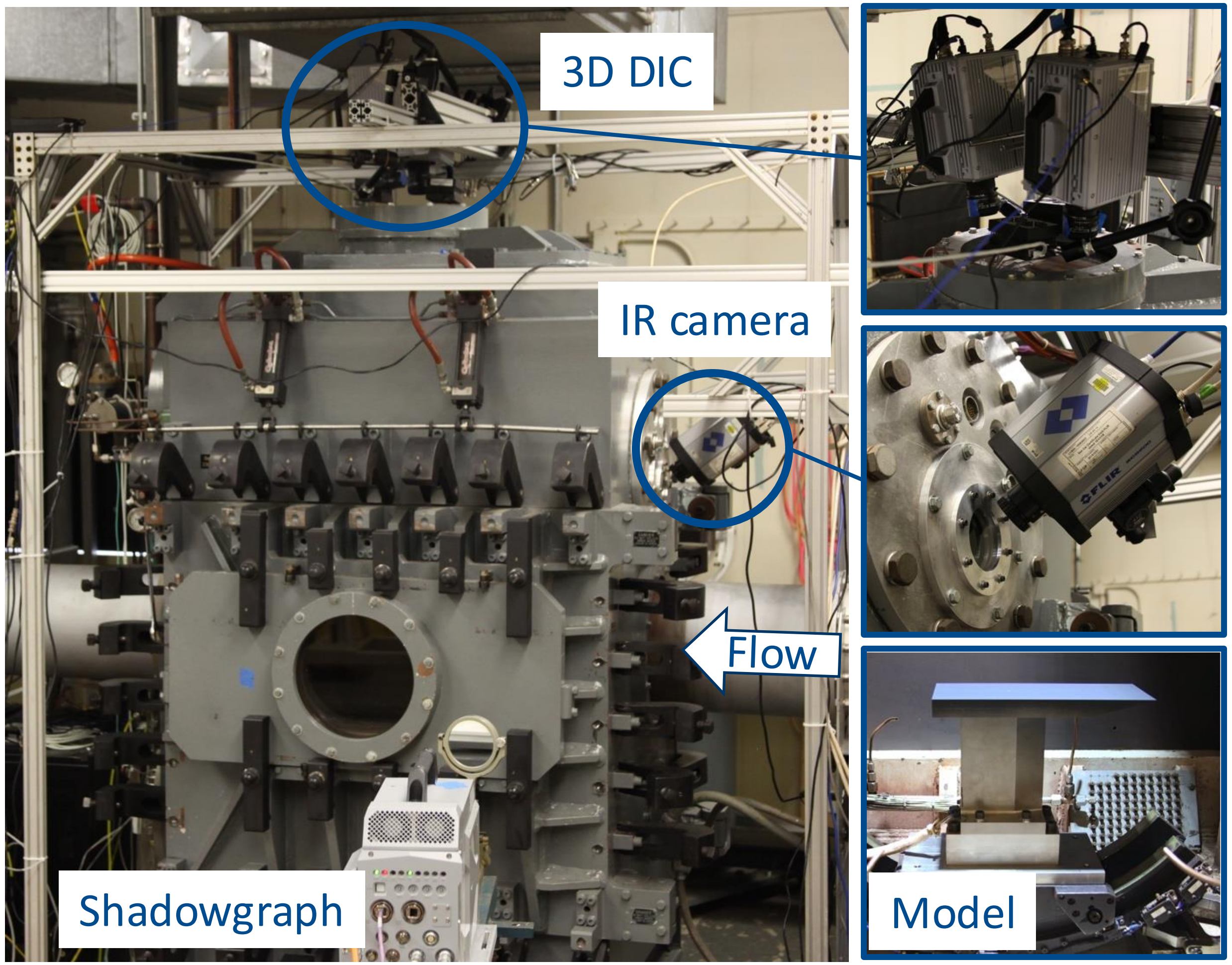
Primary Objective: Measure post-flutter dynamics of thermally buckled panel in M6 flow

M6 High Reynolds Number Facility (M6HRF)

- Free-jet with 254 mm diameter core flow
- Up to ~4 min. of test time (typically 75 sec.)
- Unit Reynolds number: 35 – 91 $\times 10^6$ m^{-1}
- Total pressure: 4.8 – 12.4 MPa
- Total temperature: 500 – 611 K

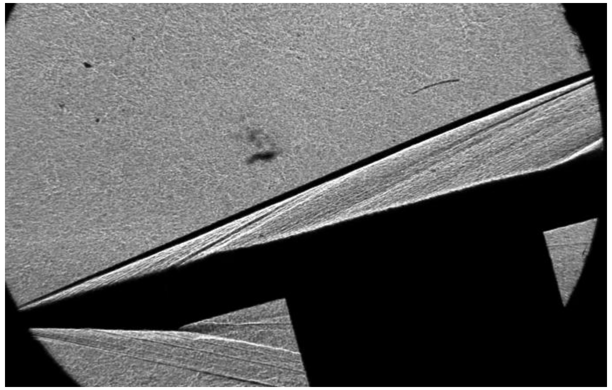
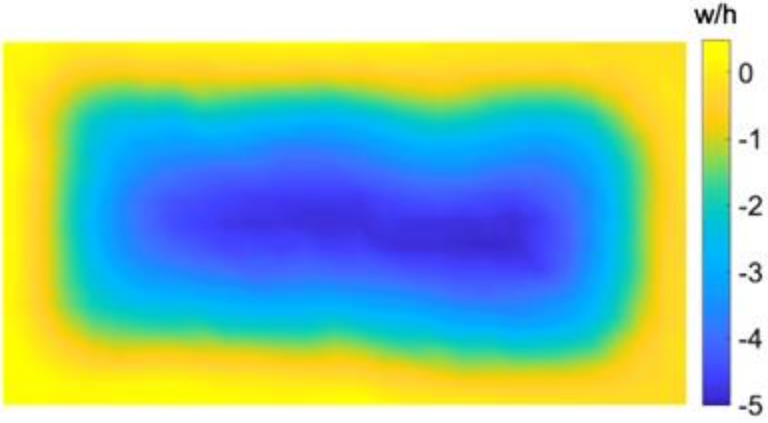
Data package:

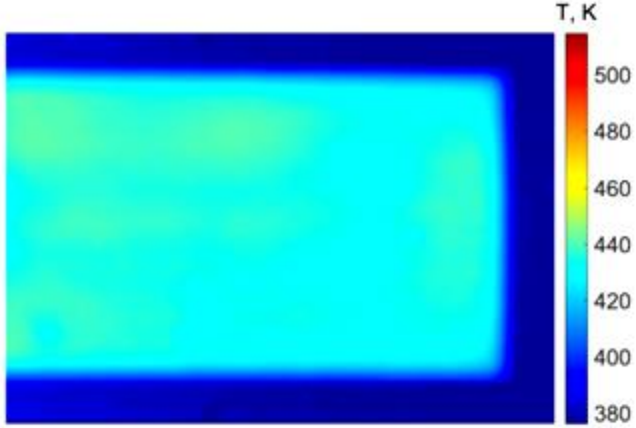
- Setup/results files packaged consistent with RC-19
- Discrete: TCs, strain gauge, cavity pressure, facility
- Full-field: DIC and IR



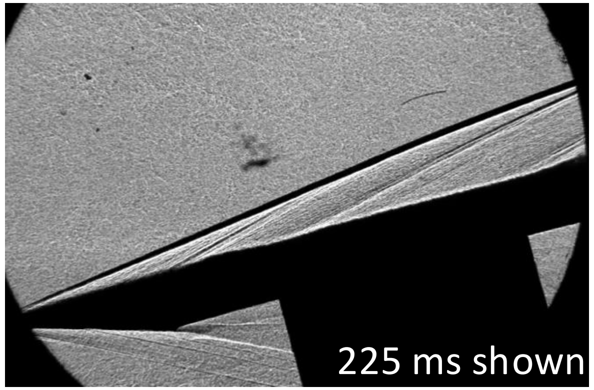
Simultaneous, Full-Field Data of Repeatable Flutter Instability

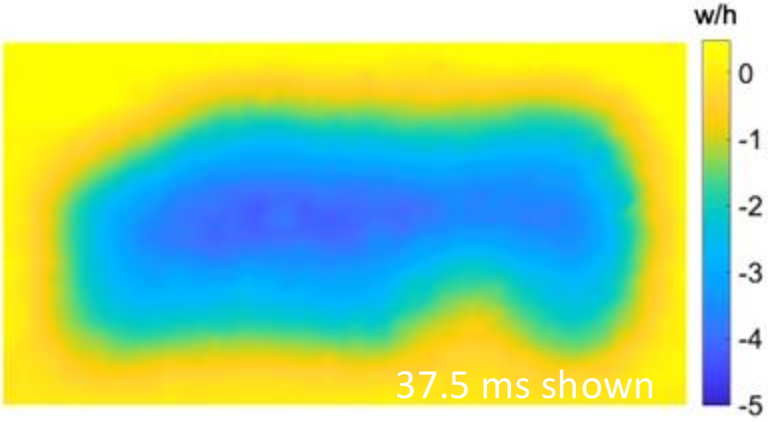
Run 29: P_0= 12.45 MPa, T_0= 571 K

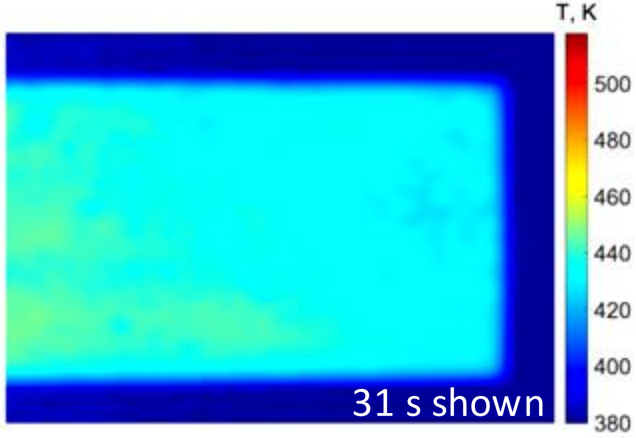





Run 31: P_0= 12.28 MPa, T_0= 563 K







Shadowgraph: 32 s @ 4,000 fps

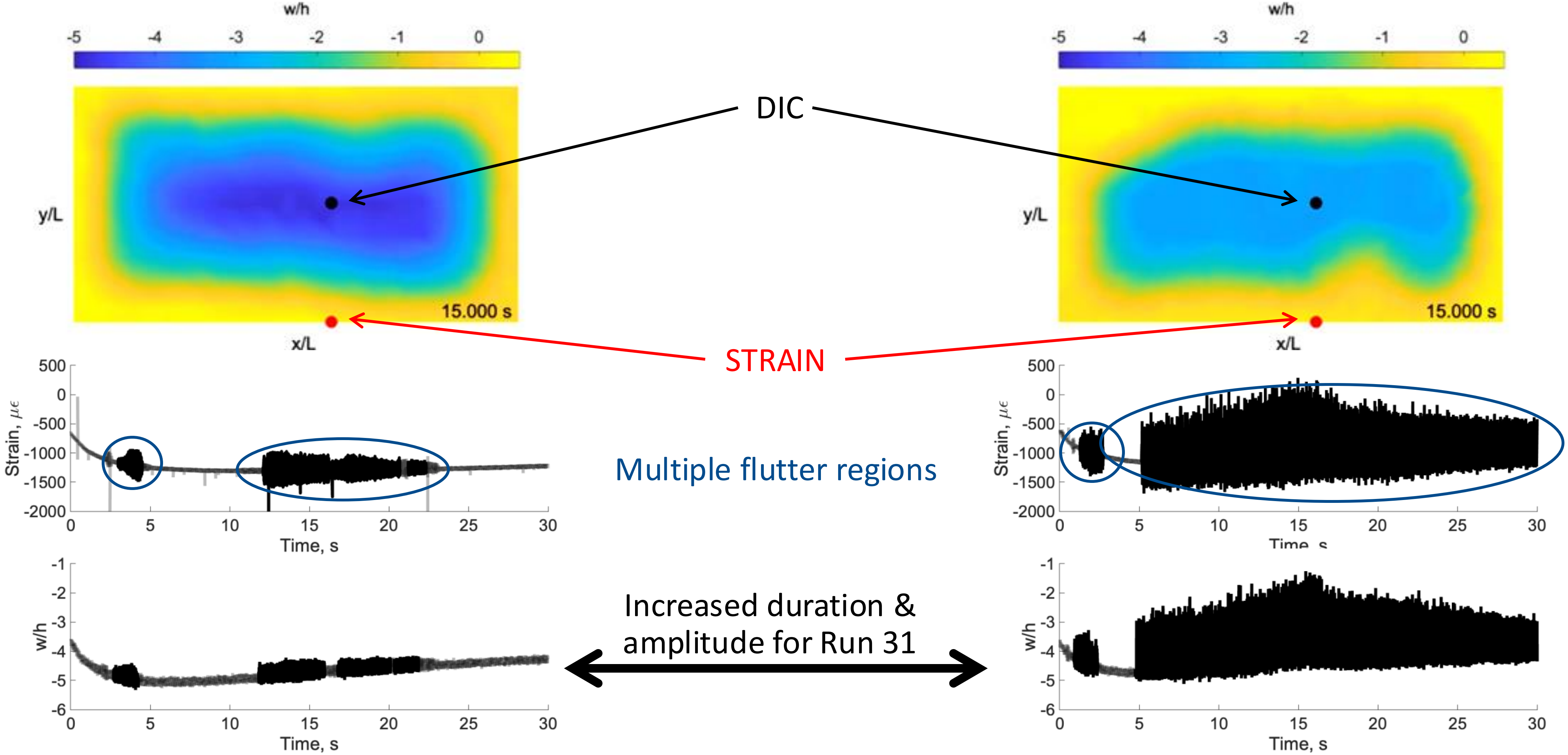
DIC: 32 s @ 4,000 fps

IR: 32 s @ 24 fps

Strain & Displacement Time Histories Highlighting Post-flutter Behavior

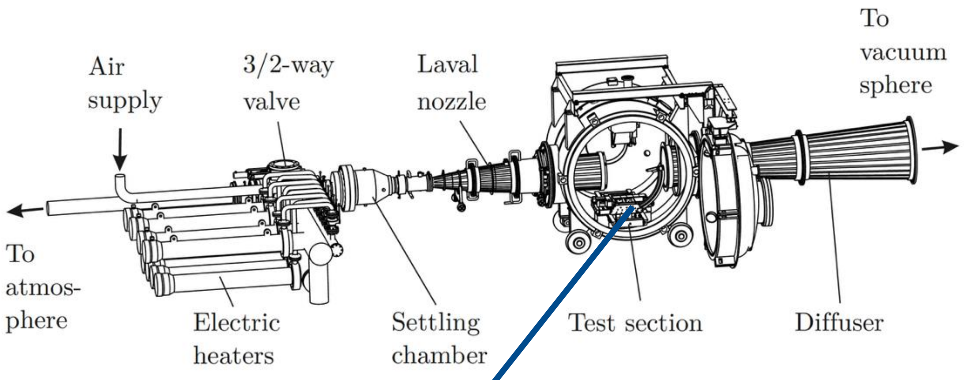
Run 29: P_0= 12.45 MPa, T_0= 571 K

Run 31: P_0= 12.28 MPa, T_0= 563 K



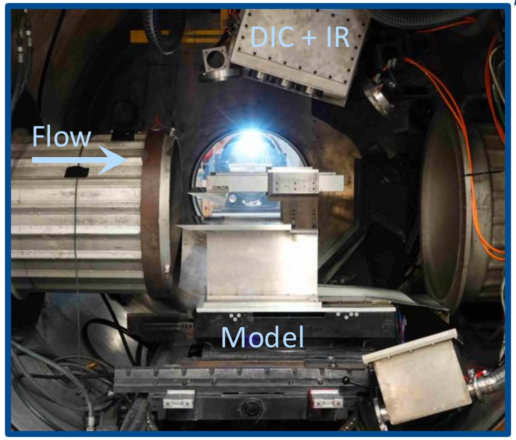
HSWG Future Directions: AFRL/DLR H2K Challenge Problem

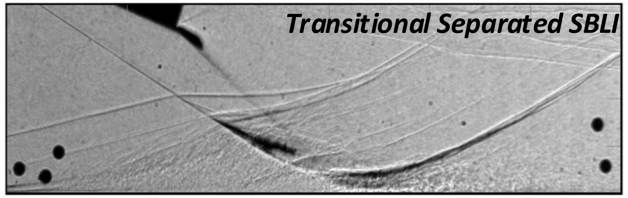
Primary Objective: Measure effects of thermal, pressure, and SBLI loading on AE/ATE instabilities

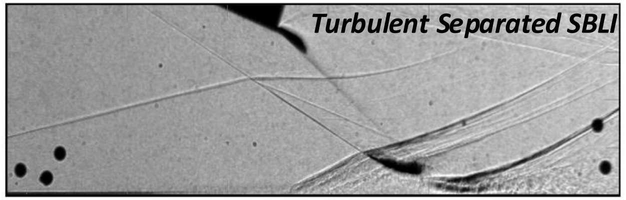


DLR Hypersonic Wind Tunnel (H2K)

- Free-jet with ~30 sec. of flow time at Mach 5.3
- Unit Reynolds number: $19.3 \times 10^6\ m^{-1}$
- Total pressure: 1250 kPa
- Total temperature: 390 – 460 K







Data package:

- Working to package setup/results files to be consistent with RC-19 and M6HRF
- Discrete: pressure (rigid only), displacement, cavity pressure, facility
- Full-field: DIC and IR

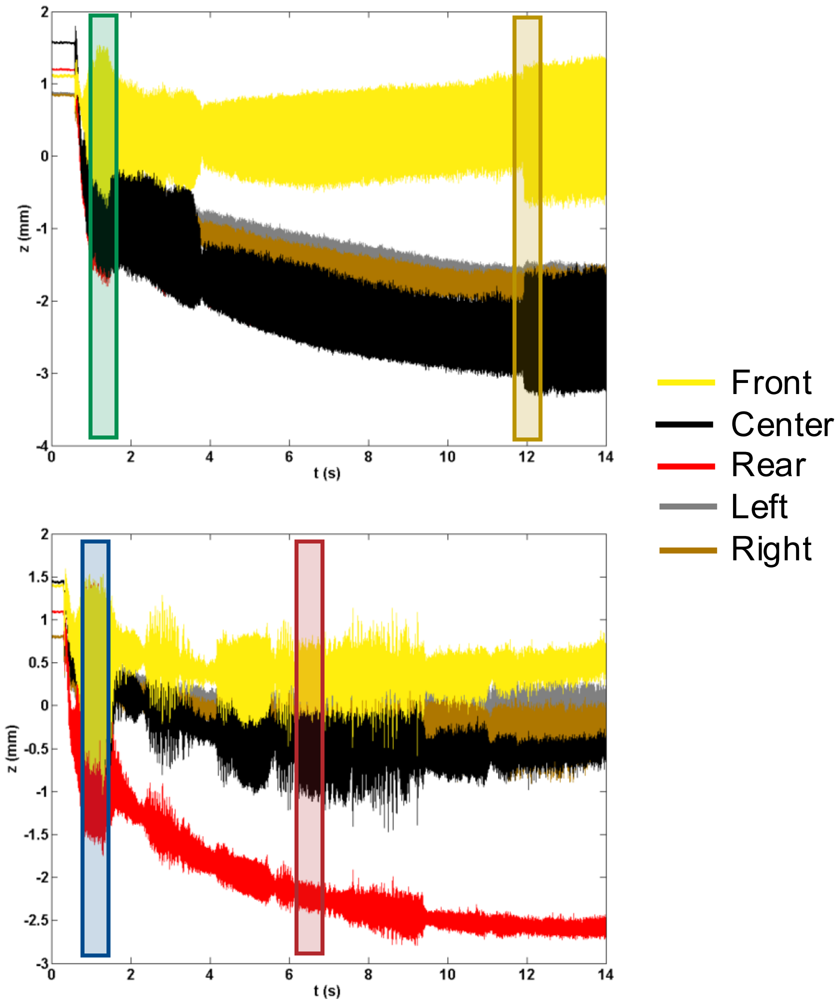
Highlights of Dynamic Instabilities Measured in H2K

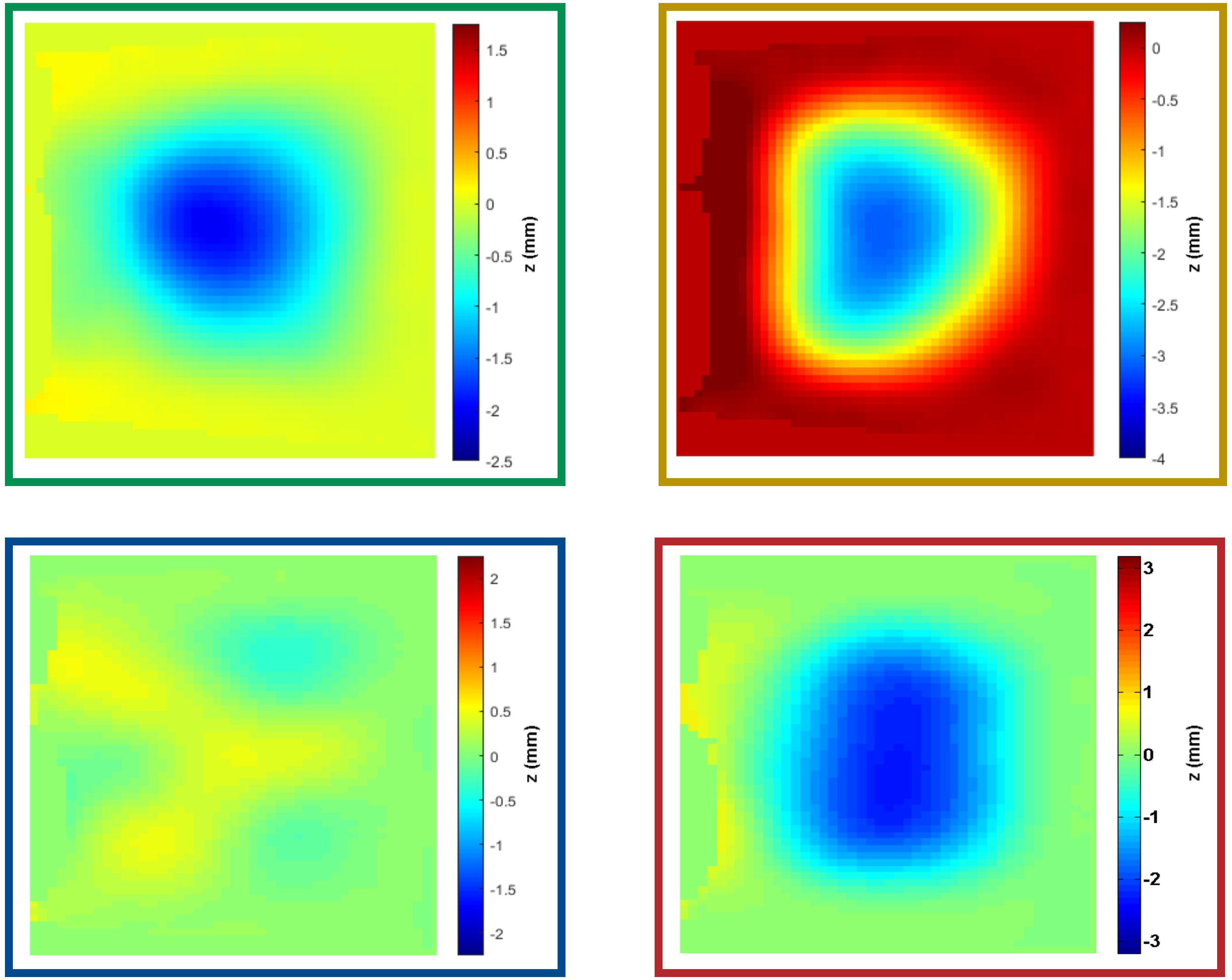
Displacement Sensors

DIC at Selected Time Intervals

20º Shock
Δx_{Shock} = 0 cm
P_0 = 1.24 MPa
T_0 = 390 K
h_{panel} = 0.7 mm

20º Shock
Δx_{Shock} = 5 cm
P_0 = 1.24 MPa
T_0 = 410 K
h_{panel} = 0.7 mm





Questions?